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A kinematic analysis of the lower limbs during running with different sports shoes

Abstract

The purpose of this study was to investigate the differences in three joint angles during running with three different types of sports shoes: Basketball Shoes (BS); Football Shoes (FS); Running Shoes (RS). 15 male subjects (age: 25±2.2years, height: 1.79±0.05m, mass: 70.8±3.4kg) participated in this experiment. During data collection, the speed of running was controlled at 3.52±0.21m/s for all three conditions. The Vicon three dimension motion analysis system was used to capture the kinematics of the lower extremity during the running test. A One-Way ANOVA was used to determine if any statistical significance existed between the three types of shoe ($p<0.05$). The results showed that there were significant differences among the three types of sports shoes, particularly at the knee joint. RS presented more flexion than BS and FS. In the frontal plane, BS showed less abduction than RS and FS, there was no significant difference in external rotation between BS and FS. When BS and FS were compared, there was less stance time during running using RS. This resulted in higher frequency of stride, but BS and FS showed greater range of motion (ROM) of the knee than RS, which may be associated with knee ligamentous injury risk. These findings indicate that running with BS and FS may result in injuries of the knee joint. RS proved to be the best choice when compared to BS and FS.

Keywords

Kinematics, sports shoes, running, gait analysis, injury

1. Introduction

It has been recorded previously that human beings have been running for millions of years [1,2]. Running is one of the most popular modes of exercise in human life. Humans globally enjoy running [3], and due to low cost and high accessibility, more and more people are becoming actively involved in this leisure activity [4]. Therefore, the choice of suitable running shoes is paramount for comfort and injury prevention. In addition to running, individuals also participate in many other kinds of sport activities, and differences in the type of sports shoes worn are very common. These sport specific shoes include, basketball, running, football and tennis shoes etc. There has been much research related to the analysis of running with specific running shoes. However, comparisons are rare in relation to analyzing running performance using other non-specific sports shoes. Although not a topic of research, running using non-specific running shoes is a common practice, particularly in the keep fit community and the non-professional leisure industry.

Previous research has illustrated that basketball and football are among the most popular sports [5]. During participation in these sports, participants may be required to run substantial distances with basketball (BS) and football shoes (FS) that are not designed specifically for running.

In support of this statement, it has been reported previously that soccer and basketball players run between 9500-12000m [6,7] and 7500m [8] during a game respectively. Therefore, research looking at running performance using these types of shoe is important and necessary.

Sports shoes not only play a key role in improving sports performance, but are crucial in preventing both acute and chronic injury. Running with different sport shoes may alter the biomechanical profile of the lower limbs during running performance, possibly contributing to the development of injury. Due to the popularity of running, associated injury is very common. This problem occurs in spite of the muscular and performance adaption that helps prevent the risk of running associated injury [9,10]. Stacoff concluded that the eversion/inversion motion of the ankle was associated with rear foot pronation, which has been seen as an important factor contributing to lower limb overuse injuries [11,12]. Previous research has investigated if ankle joint injury was one of the most common sport-related injury in running [13]. Running for long periods may also contribute to further ankle injury such as chronic ankle instability (CAI) [14]. Knee injury is the most common lower limb injury reported during sustained running. In addition, knee injury is more serious and costly than other joints [15,16]. Prior research has demonstrated that most of the knee injuries recorded happened when the knee was close to full extension [17]. Additionally, the decreased knee flexion and the increased abduction have been linked to promote patellofemoral pain syndrome (PFPS) and anterior cruciate ligament (ACL) injury. Both of these injuries not only affect sports participation, but also increase the risk of osteoarthritis [16,18,19]. In addition, knee injury is also related to hip joint motion and increased hip adduction and internal rotation are commonly seen during ACL injury [17]. Considering the relationship between running kinematics and running injury, it is necessary to reliably, and accurately, evaluate individual running kinematics. This information will be both crucial and essential in preventing running associated injury [20].

In summary, the purpose of this study was to determine if there were any kinematic differences between the three types of sports shoes used during running performance. A further aim was to analyze any potential effects that the differences could cause in relation to joint injury. Finally, the findings from the study may be useful in identifying the correct sport shoes that are the best for running and cause less joint injury. We hypothesized that running with specifically designed running shoes (RS) would be better than running using the other two non-specifically designed sport shoes.

2. Methods

This study invested the kinematics during running with different sports shoes, and was part of a larger research project to determine which sport shoes would be biomechanically beneficial for enhancing running performance [21,22]. The reason for choosing males to participate in this study was because of the large participation levels of males playing basketball and football [23]. Females may also have less physical strength than males [24]. These factors were taken into consideration to eliminate confounding gender differences in running mechanics [25].

2.1. Subjects

Fifteen healthy male (age: 25±2.2years, height: 1.79±0.05m, mass: 70.8±3.4kg) runners who play basketball or football regularly and also run three times a week volunteered to participate in this study. They were all free from lower limb injury for 6 months and were not recovering from injury. All subjects were habitually shod recreational runners with a rear-foot strike and they provided written informed consent prior to the commencement of the study.

2.2. Shoes conditions

The three types of sports shoes examined, including basketball shoes (BS), running shoes (RS), and football shoes (FS). All of the test shoes were 42 (US). Subjects were required to run on the ground using the following dimensions: BS (mass: 704g/pair, heel height: 4.0cm), RS (mass: 524g/pair, heel height: 3.5cm) and FS (mass: 510g/pair, heel height: 2.0cm).

Fig. 1. Basketball shoes (BS), running shoes (RS), football shoes (FS) respectively.

2.3. Elastic modulus test

The materials of the sports shoes midsoles were measured and calculated by (Fig.2), and we tested it under normal temperature and humidity.

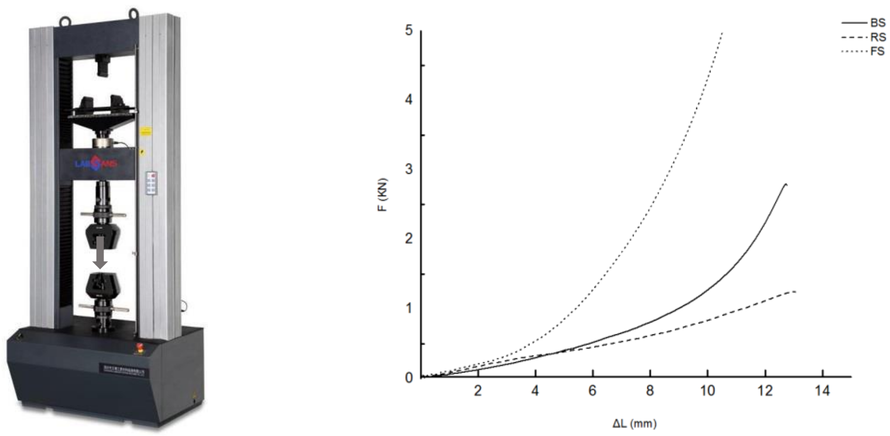

Fig. 2. The elastic modulus test system (left). ΔL represented the deformation of the materials after compressing, and F represented the force to press the materials.

2.4. Experiment protocol and procedure

Subjects ran with three types of testing shoes on the treadmill, they ran on the treadmill 8 minutes for giving warm-up, because of the differences among individuals, each subject select the most suitable running speed, and the speed of running was used in all conditions, we did the warm-up part was to get adaption to do the test on the ground. The average pace was 3.52±0.21m/s.

Then, following the warm-up, participants ran in the three conditions: basketball shoe, running shoes and football shoes. There was about 5 minutes for rest between different conditions. Five valid trials (correct foot strike pattern, speed, captured all markers) were included into analysis for each subject.

The lower limb joins' kinematic data were collected with an eight-camera Vicon motion analysis system (200Hz, Vicon MX, Vicon Motion System Ltd., Oxford, UK), sixteen reflective markers (diameter: 14mm) were placed on the left and right lower limbs according to the Plug-in Gait Model [26], including anterior-elite iliac spine, posterior-elite iliac spine, lateral mid-thigh, lateral knee, lateral mid-shank, lateral malleolus, second metatarsal head and calcaneus.

2.5. Statistical analysis

Statistical analysis was performed with SPSS 17.0 software (SPSS for windows, Chicago, IL, USA), the collected ROM data of lower limb joint were tested using One-way ANOVA among the three types of sports shoes, statistical differences were established at $p<0.05$. We used the NCSS-PASS 11.0.7 to calculate the power, power analysis was needed to assess the reliability of the test before the study, alpha level was set at 0.05.

3. Results

In this study we collected the data of right leg, the joints' ranges of motions (ROM) of ankle, knee and hip were calculated by this motion analysis system. The lower limbs ROM during the stance of running were shown in Table 1.

Table 1

ROM (Range of motion) of the lower limb during the stance phase of running (degrees)

			BS	RS	FS	p-Values
Ankle	Sagittal	Mean	46.68	43.12	48.61	0.02*
						0.15
		SD	3.95	2.04	2.74	<0.001***
	Frontal	Mean	5.79	4.08	4.85	<0.001*
						<0.001**
		SD	0.49	0.57	0.60	0.05***
	Horizontal	Mean	25.36	18.99	21.92	<0.001*
						<0.003**
		SD	2.54	2.25	2.81	0.021***
Knee	Sagittal	Mean	35.56	28.67	28.37	<0.001*
						<0.001**
		SD	2.30	2.43	1.67	0.79
	Frontal	Mean	18.87	9.89	14.72	<0.001*
						<0.001**
		SD	1.43	1.14	2.12	<0.001***
	Horizontal	Mean	28.59	15.98	20.48	<0.001*
						<0.001**
		SD	2.13	2.17	1.79	<0.001***
Hip	Sagittal	Mean	52.12	47.03	55.38	0.067
						0.134
		SD	5.02	1.47	5.40	0.004***
	Frontal	Mean	11.55	12.15	10.91	0.47
						0.44
		SD	0.87	0.91	1.28	0.49
	Horizontal	Mean	20.32	19.66	17.18	0.056
						0.025**
		SD	2.29	2.21	2.25	0.846

*Note. * presented there was a significant difference between basketball shoes (BS) and running shoes (RS); ** presented there was a significant difference between basketball shoes (BS) and football shoes (FS); *** presented there was a significant difference between running shoes (RS) and football shoes (FS). The significances for p<0.05.*

In the sagittal plane, the ankle plantarflexion degrees of RS was -9.53°，which was less than BS and FS footwear conditions. The knee adduction of BS was much greater than RS and FS, and in the horizontal plane, the hip rotation degrees of BS was also greater than the other two conditions (Table 2).

Table 2
Comparisons mean (SD) of ankle, keen, hip joints angle during running with basketball shoes (BS), running shoes (RS) and football shoes (FS) respectively.

		BS	RS	FS
	Peak angle (degrees)			
Sagittal	Ankle dorsiflexion	32.80 (1.27)	33.59 (1.78)	32.21 (1.15)
	Knee flexion	40.86 (2.47)	44.60 (1.52)	29.57 (1.06)
	Hip flexion	33.55 (4.42)	33.59 (2.20)	32.21 (2.90)
	Ankle plantarflexion	-13.88 (3.64)	-9.53 (2.72)	-16.40 (2.90)
	Knee extension	5.30 (1.15)	15.93 (2.72)	1.21 (0.87)
	Hip extension	-18.57 (0.98)	-20.58 (0.78)	-21.34 (2.86)
Frontal	Ankle inversion	5.87 (0.26)	6.01 (0.50)	5.01 (0.21)
	Knee adduction	19.98 (0.70)	9.89(1.14)	12.20 (2.58)
	Hip adduction	15.46 (0.81)	15.33 (0.99)	14.62 (0.92)
	Ankle eversion	0.08 (0.44)	1.93 (0.59)	0.16 (0.67)
	Knee abduction	0.79 (1.49)	-0.68 (0.57)	5.37 (0.74)
	Hip abduction	3.96 (0.72)	3.32 (0.53)	3.71 (0.54)
Horizontal	Ankle int. rotation	2.39 (2.49)	-5.71 (2.94)	2.23 (3.12)
	Knee int. rotation	2.48 (1.03)	8.46 (0.73)	-4.13 (0.94)
	Hip int. rotation	17.85 (1.27)	15.18 (1.86)	14.61 (1.49)
	Ankle ext. rotation	-22.97 (1.00)	-24.69 (1.23)	-19.60 (0.88)
	Knee ext. rotation	-26.12 (1.68)	-7.59 (1.81)	-24.61 (1.46)
	Hip ext. rotation	-2.47 (2.64)	-2.28 (4.06)	-2.57 (2.96)

As represented in the Fig. 3, running with RS showed less stance time than the other two testing shoes. In the sagittal plane, RS exhibited greater dorsiflexion and less plantarflexion than BS and FS, there was no significant difference between BS-RS and BS-FS, but running with FS exhibited more plantarflexion than the other two shoes ($p<0.001$). In the frontal plane, there were significant differences in RS-FS ($p<0.001$), we found running with RS showed more ankle inversion and less eversion, and in the horizontal plane, it presented largest external rotation. However, there was no significant difference between BS and FS in the ankle internal rotation, the values both of them were greater than RS. As described in Table 1, RS showed less ROM of joint ankle in the three dimensions than BS and FS.

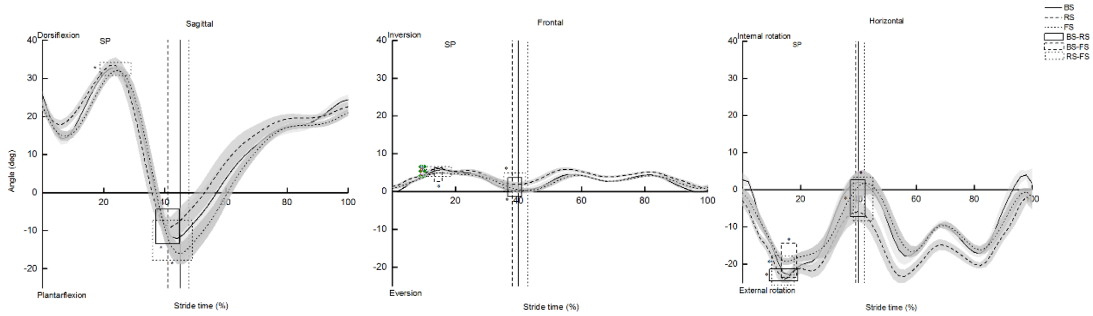

Fig. 3. *Angular motion of ankle in sagittal, frontal and horizontal planes during running with basketball shoes (——), running shoes (- - -) and football shoes (-----). SP represented standing phase of running.*

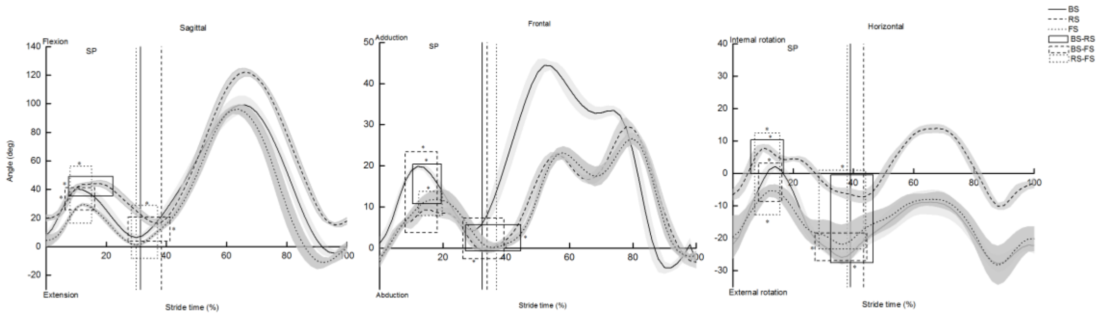

Fig. 4. *Angular motion of knee in sagittal, frontal and horizontal planes during running with basketball shoes (——), running shoes (- - -) and football shoes (-----). SP represented standing phase of running.*

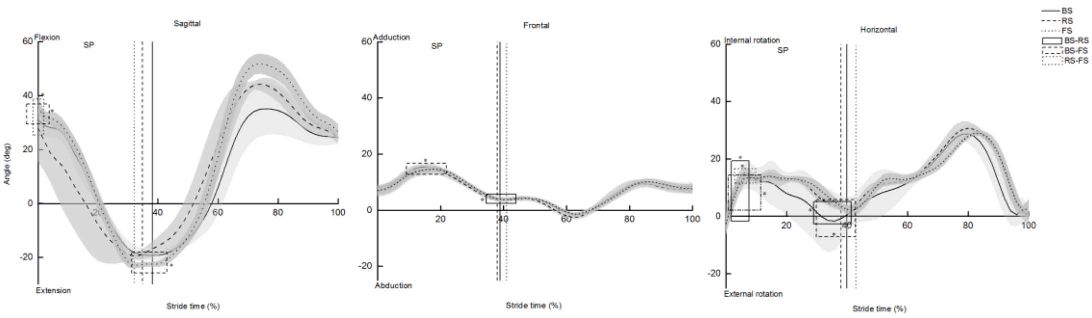

Fig. 5. *Angular motion of hip in sagittal, frontal and horizontal planes during running with basketball shoes (——), running shoes (- - -) and football shoes (-----). SP represented standing phase of running.*

Graphically, at the joint of knee, it could be observed that there were significant differences in the knee flexion/extension in the sagittal plane (Fig. 4), FS condition had less stance time than BS and RS, and in the toe-off phase (last 5% of stance phase), FS represented greater extension. Compared to RS and FS, BS showed more adduction. Significant differences in the horizontal plane about the joints' ROM was existed, contrast to BS and FS, RS represented less ROM. BS showed larger ROM in the three dimensions.

As shown in the Fig. 5, RS presented less hip flexion/extension at the joint of hip in the sagittal plane, however, and in the horizontal plane, BS exhibited more internal rotation than RS and FS. According to the Table 1, we could find the ROM of BS was larger than RS and FS in the horizontal plane.

4. Discussion

The aim of this study was to determine whether there were some differences among the three types of sports shoes during running, and what the influences they could cause. Our first hypothesis was that running with running shoes (RS) would be better than the other two shoes, and the second hypothesis was running with FS could be better than BS footwear condition. Within this study, we observed that running with BS resulted in lower limb joints injuries more likely. It presented greater ankle plantarflexion and knee abduction, what's more, greater hip internal rotation was observed in this running condition. In contrast, running with running shoes (RS) showed less joint ROM than BS and FS.

In the perspective of the kinematics, there were some findings in our study, firstly, in the Table 1, running with RS presented the minimalist range of motion (ROM), there were significant differences between the values of ROM ($p<0.05$) in different footwear conditions. Running with FS showed a greater ROM in the sagittal plane of the joint ankle, the FS peak angle of ankle plantarflexion was much larger than RS (FS=-16.4°, RS=-9.53°), it was strengthened the result which larger plantarflexion was associated with the chronic injuries [27], another previous study showed that a more ankle plantarflexion, a more inverted ankle, a more possibility of chronic ankle instability [28], however, inability to control lower extremity segments in the frontal and horizontal planes resulting in large knee abduction angle and increased internal knee abduction has been associated with patellofemoral pain. It was also a good evidence to prove this finding in our current study. Anterior cruciate ligament (ACL) and patellofemoral joint (PFJ) injuries could be found in basketball and football player widely, these injuries were with decreased knee flexion, increased hip internal rotation and increased knee abduction [29,30,31], frontal plane motion at the hip and horizontal motion at the hip and knee, which play a part in increasing ACL and PFJ injuries [30]. In the Fig 3 and Fig 4, there were significant differences in the knee and the hip in the horizontal planes, running with RS showed less knee external rotation in the horizontal plane (Fig. 3), however running with RS presented less knee external rotation, and there was no significant difference between BS footwear condition and FS footwear condition (Table. 3), RS also showed less hip internal rotation in the horizontal plane (Fig. 4), comparing the data of three running conditions, running with RS was better than the other two footwear conditions in the perspective of the running injury, the first hypothesis of our research was supported.

It was observed in our study, running shoes (FS) condition showed less stance time than basketball shoes (BS) and football shoes (FS) conditions, it could be referred in previous study, which investigated the effect of the different step rates on plantar pressures during running, they illustrated that running with increased step rate would decrease the plantar pressure, these findings can be useful as a strategy increasing step rate during running to reduce the plantar pressure in the rearfoot. [32]. It could be found running with football shoes (FS) presented more stance time than the other two footwear condition, Ribeiro noted greater rearfoot plantar was associated with the heel pain [33], but in our study, there was no statistics about plantar pressure, this is what we should do in the future study.

Several studies paid attention to the effects of the shoe mass during running, Divert illuminated that there was a significant mass effect on oxygen consumption, there were 12 subjects in that study, he compared the six running conditions, including different mass of shoes during shod running [34]. As wearing shoes has been observed to alter running mechanics [35,36], many researchers focused on shoes mass, Burkett found shoes mass was the main factor for the higher energy consumption in shod running [37]. Comparing the mass of basketball shoes (BS), running shoes (RS) and football shoes (FS), running with BS would cost more energy than RS and FS, and it was likely linked to the running fatigue.

Midsole longitudinal bending stiffness (LBS) is considered to be crucial in running shoe development. Energy absorption at the metatarsal phalangeal joint (MPT) is reduced with increasing LBS in running [38]. RS showed less stiffness than BS and FS, training in shoes with very low LBS resulted in higher increases in lower leg muscles cross sectional areas and strength capacities compared to training in shoes with regular bending stiffness, however runners with low strength capacities might lead to fatigue of plantarflexing easily [39], it observed selecting BS was better than FS from the aspect of materials function.

There are several limitations of the current study should be considered, first, we just focused on the kinematics, not refer to the side of kinetics, in the future study, we need to do more works about connecting the kinematics with kinetics, it would be better for assessing and preventing running injury. Then, we limited our analysis just to the stance phase, and the other part of the gait we didn’t mention, swing phase also played an important role in the gait, therefore, we should do detailed study of running gait including all phases in the future. Finally, we did not assess the oxygen during running, it was associated with the energy assumption and fatigue, additionally the running injury.

5. Conclusion

In conclusion, findings from this study indicated that the changes of lower limb joint during running with basketball shoes (BS), running shoes (RS), and football shoes (FS). Running with RS is better than BS and FS, it can gain less trend to get knee injury, but running with BS cannot be a good choice, which will be associated with some injury of knee and hip, furthermore, running with BS may consume more energy, it should be paid attention in our life.

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